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U. S. DEPARTMENT OF AGRICULTURE.
BUREAU OF PLANT INDUSTRY—BULLETIN NO. 83.
B. T. GALLOWAY, *Chief of Bureau.*

THE

VITALITY OF BURIED SEEDS.

BY

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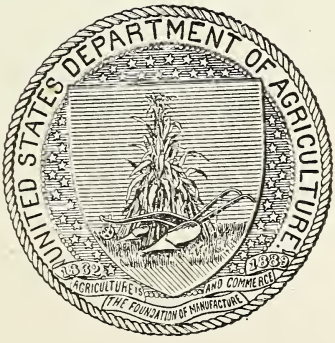
ISSUED AUGUST 4, 1905.



WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1905.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., May 29, 1905.

Sir: I have the honor to transmit herewith, and to recommend for publication as Bulletin No. 83 of the series of this Bureau, the accompanying technical paper entitled "The Vitality of Buried Seeds."

The experiments discussed were undertaken in order to determine the length of time that seeds of different species of plants will retain their vitality when buried at various depths. Seeds of both cultivated and wild plants were used, but special attention was given to weed seeds in order to ascertain what weeds can be eradicated by deep plowing and how long the soil must remain undisturbed before the vitality of the seeds will be entirely destroyed. The results of the first year's experiments show that the noxious character of weeds is closely associated with the length of time the seeds will remain viable in the soil, and that many weeds can be eradicated by plowing. Much additional information is given, showing the relative resistance of the seeds of cultivated plants and of those commonly designated as weeds, and the influence upon the preservation of vitality of the depth of burial, of hard seed coats, and of hulled as compared with unhulled seed.

This paper was prepared by J. W. T. Duvel, Assistant in the Seed Laboratory, and has been submitted with a view to publication.

The accompanying illustrations are necessary for a complete understanding of the paper.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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THE VITALITY OF BURIED SEEDS.

INTRODUCTION.

The preservation of the vitality of seeds when buried in the soil and the awakening of metabolic activity in such seeds on being exposed to conditions favorable to their germination are equally as important to the practical farmer as to the scientist. The intelligent farmer in order to combat noxious plants successfully should know how much time must elapse after heavy crops of weeds of various sorts are turned under before the ground can be plowed again with safety. He should also know what plants he can hope to eradicate in this way, for with many of our worst weeds this method would result only in failure. In fact, the reason why the majority of our most persistent weeds are so difficult to eradicate is because their seeds are capable of retaining their vitality for a number of years when buried in the soil. It thus becomes important to know how different species of seeds behave when buried under similar conditions, and how seeds of the same species behave when buried under different conditions.

KINDS OF SEEDS BURIED.

So much has already been written on the germination of seeds that have remained dormant in the soil for a number of years, in some cases even for centuries, that it seemed desirable to determine with some degree of accuracy the length of time that certain seeds will retain their vitality when buried in the soil under known conditions. Accordingly, in the autumn of 1902, 112 different samples of seeds were selected for these experiments, as follows:

TABLE I.—*List of seeds selected for the experiments.*

Laboratory test number.	Kind of seed.	Sample number.	Burial number as given on diagram.
	Poaceæ (grass family):		
16173	*Agropyron repens* (L.) Beauv. (couch grass)	100	31
16174	*Avena fatua* L. (wild oat)	71	9
16175	*Avena sativa* L. (oats)	24	8
16176	*Bromus secalinus* L. (cheat, chess)	34	36
16177	*Bromus racemosus* L. (upright chess, smooth brome-grass)	33	37
16178	*Chaetochloa verticillata* (L.) Scribn. (foxtail)	108	66
16179	*Chaetochloa glauca* (L.) Scribn. (yellow foxtail)	46	33
16180	*Chaetochloa viridis* (L.) Scribn. (green foxtail)	5	67
16181	*Eleusine indica* (L.) Gaertn. (wire-grass, crab-grass)	26	72
16182	*Elymus virginicus* L. (Virginia wild rye)	77	15
16183	*Elymus canadensis* L. (nodding wild rye)	74	13
16184	*Elymus triticoides* Buckl. (wild wheat)	69	14

TABLE 1.—*List of seeds selected for the experiments*—Continued.

Laboratory test number.	Kind of seed.	Sample number.	Burial number as given on diagram.
	Poaceæ (grass family)—Continued.		
16185	*Festuca elatior* L. (meadow fescue)	38	35
16186	*Hordeum sativum* Jessen. (barley)	23	12
16187	*Panicum virgatum* L. (tall, smooth panicum)	70	32
16188	*Phalaris arundinacea* L. (reed canary grass)	93	34
16189	*Phleum pratense* L. (timothy)	112	68
16190	*Poa pratensis* L. (Kentucky bluegrass)	75	73
16191	*Secale cereale* L. (rye)	25	11
16192	*Sporobolus airoides* Torr. (hair-grass drop-seed)	12	69
16193	*Sporobolus cryptandrus* (Torr.) A. Gray (sand drop-seed)	63	71
16194	*Sporobolus cryptandrus* (Torr.) A. Gray (sand drop-seed—hulled seed)	13	70
16195	*Triticum aestivum* L. (wheat)	22	10
16196	*Zea mays* L. (corn—Boone County white)	14	1
16197	*Zea mays* L. (sweet corn—early Concord)	15	2
	Cyperaceæ (sedge family):		
16198	*Cyperus esculentus* L. (yellow nut-grass)	7	74
	Liliaceæ (lily family):		
16199	*Allium cepa* L. (onion)	27	39
	Convallariaceæ (lily-of-the-valley family):		
16200	*Asparagus officinalis* L. (asparagus)	32	16
	Moraceæ (mulberry family):		
16201	*Cannabis sativa* L. (hemp)	4	17
	Urticaceæ (nettle family):		
16202	*Boehmeria nivea* Gaud. (ramie)	2	75
	Polygonaceæ (buckwheat family):		
16203	*Fagopyrum fagopyrum* (L.) Karst. (buckwheat)	21	18
16204	*Polygonum pennsylvanicum* L. (Pennsylvania persicaria, smartweed)	9	40
16205	*Polygonum persicaria* L. (lady's-thumb, smartweed)	10	78
16206	*Polygonum scandens* L. (climbing false buckwheat)	11	41
16207	*Rumex salicifolius* Weinm. (willow-leaved dock)	107	76
16208	*Rumex crispus* L. (curled dock), not cleaned	103	39
16209	*Rumex obtusifolius* L. (broad-leaved dock, bitter dock)	102	77
	Chenopodiaceæ (goosefoot family):		
16210	*Axyris amaranthoides* L. (Russian pigweed)	1	81
16211	*Beta vulgaris* L. (sugar beet)	72	19
16212	*Chenopodium album* L. (lamb's quarters, white goosefoot)	96	79
16213	*Chenopodium hybridum* L. (maple-leaved goosefoot)	62	80
	Amaranthaceæ (amaranth family):		
16214	*Amaranthus retroflexus* (rough pigweed)	83	82
	Phytolaccaceæ (pokeweed family):		
16215	*Phytolacca americana* L. (poke, pigeon berry)	104	42
	Portulacaceæ (purslane family):		
16216	*Portulaca oleracea* L. (purslane, pussley)	86	83
	Silenaceæ (pink family):		
16217	*Agrostemma githago* L. (corn cockle)	16	43
16218	*Alsine media* L. (common chickweed)	110	84
16219	*Vaccaria vaccaria* (L.) Britton (cowherb)	55	44
	Brassicaceæ (mustard family):		
16220	*Brassica nigra* (L.) Koch (black mustard)	67	87
16221	*Brassica oleracea* L. (cabbage)	17	45
16222	*Brassica campestris* L. (turnip)	40	88
16223	*Bursa bursa-pastoris* (L.) Britton (shepherd's purse)	3	89
16224	*Erysimum cheiranthoides* L. (wormseed, treacle mustard)	58	47
16225	*Neslia paniculata* (L.) Desv. (ball mustard)	85	46
16226	*Sisymbrium altissimum* L. (tall sisymbrium)	78	86
16227	*Thlaspi arvense* L. (field penny cress)	60	85
	Rosaceæ (rose family):		
16228	*Potentilla monspeliensis* L. (rough cinquefoil)	73	90
	Caesalpiniaceæ (senna family):		
16229	*Cassia marylandica* L. (wild senna, American senna)	52	48
	Fabaceæ (pea family):		
16230	*Lespedeza frutescens* (L.) Britton (wand-like bush clover)	43	52
16231	*Medicago sativa* L. (alfalfa, lucern)	59	49
16232	*Phaseolus vulgaris* L. (bean)	20	4
16233	*Pisum sativum* L. (pea)	19	5
16234	*Robinia pseudacacia* L. (locust tree, false acacia)	37	51
16235	*Trifolium hybridum* L. (alsike clover)	50	93
16236	*Trifolium pratense* L. (red clover)	49	50
16237	*Trifolium pratense* L. (red clover) harvest of 1900	54	91
16238	*Trifolium pratense* L. (red clover) hard seed from No. 16237	68	92
16239	*Trifolium repens* L. (white clover)	41	94
16240	*Vigna catjang* Walp. (Iron cowpea)	42	3
	Linaceæ (flax family):		
16241	*Linum usitatissimum* L. (flax, linseed)	30	53
	Anacardiaceæ (sumac family):		
16242	*Rhus glabra* L. (scarlet sumac)	47	20
	Malvaceæ (mallow family):		
16243	*Abutilon abutilon* (L.) Rusby. (velvet leaf)	111	54
16244	*Gossypium hirsutum* L. (cotton)	18	6
16245	*Hibiscus militaris* Cav. (halberd-leaved rose mallow)	31	55

TABLE I.—*List of seeds selected for the experiments*—Continued.

Laboratory test number.	Kind of seed.	Sample number.	Burial number as given on diagram.
	Hypericaceæ (St. John's wort family):		
16246	*Ascyrum hypericoides* L. (St. Andrew's cross)	44	95
	Onagraceæ (evening primrose family):		
16247	*Onagra biennis* (L.) Scop. (common evening primrose)	8	96
	Apiaceæ (carrot family):		
16248	*Apium graveolens* L. (celery)	94	57
16249	*Pastinaca sativa* L. (parsnip, wild)	95	56
	Oleaceæ (olive family):		
16250	*Fraxinus americana* L. (white ash)	105	21
	Convolvulaceæ (morning-glory family):		
16251	*Convolvulus sepium* L. (hedge bindweed, great bindweed)	56	23
16252	*Ipomoea lacunosa* L. (small-flowered white morning-glory)	81	22
	Cuscutaceæ (dodder family):		
16253	*Cuscuta polygonorum* Engelm. (smartweed dodder)	63	98
16254	*Cuscuta epilinum* Weihe. (flax dodder)	82	97
	Verbenaceæ (vervain family):		
16255	*Verbena hastata* L. (blue vervain)	66	100
16256	*Verbena urticifolia* L. (white vervain, nettle-leaved vervain)	79	99
	Solanaceæ (potato family):		
16257	*Capsicum annuum* L. (red pepper)	39	59
16258	*Datura tatula* L. (purple stramonium, jimson weed)	106	61
16259	*Lycopersicon lycopersicon* (L.) Karst. (tomato)	45	60
16260	*Nicotiana tabacum* L. (tobacco)	99	101
16261	*Solanum nigrum* L. (black nightshade, garden nightshade)	61	58
	Scrophulariaceæ (figwort family):		
16262	*Verbascum thapsus* L. (great mullen)	76	102
	Plantaginaceæ (plantain family):		
16263	*Plantago lanceolata* L. (ribwort, ribgrass, buckhorn)	88	105
16264	*Plantago major* L. (common plantain)	91	103
16265	*Plantago rugelii* Dec. (Rugel's plantain, broad plantain)	65	104
	Cucurbitaceæ (gourd family):		
16266	*Citrullus citrullus* (L.) Karst. (watermelon)	6	26
16267	*Cucumis melo* L. (muskmelon)	26	25
16268	*Cucumis sativus* L. (cucumber)	48	24
	Cichoriaceæ (chicory family):		
16269	*Lactuca scariola* L. (prickly lettuce)	98	107
16270	*Lactuca sativa* L. (lettuce)	28	62
16271	*Taraxacum erythrospermum* Andrz. (red-seeded dandelion)	90	106
	Ambrosiaceæ (ragweed family):		
16272	*Ambrosia artemisiaefolia* L. (ragweed)	87	63
16273	*Ambrosia trifida* L. (great ragweed)	53	28
16274	*Xanthium pennsylvanicum* Wallr. (Pennsylvania clotbur, cocklebur)	51	27
	Asteraceæ (aster family):		
16275	*Arctium lappa* L. (burdock, clotbur)	101	112
16276	*Bidens frondosa* L. (black beggar ticks)	84	64
16277	*Cardnus arvensis* (L.) Robs. (Canada thistle)	80	111
16278	*Chrysanthemum leucanthemum* L. (whiteweed, oxeye daisy)	92	110
16279	*Grindelia squarrosa* (Pursh.) Dunal. (broad-leaved gum plant)	89	108
16280	*Helianthus annuus* L. (common sunflower, wild)	97	29
16281	*Helianthus annuus* L. (common sunflower, cultivated)	29	7
16282	*Onopordon acanthium* L. (cotton thistle, scotch thistle)	109	65
16283	*Rudbeckia hirta* L. (black-eyed Susan)	57	109
	Pinaceæ (pine family):		
16284	*Pinus virginiana* Mill. (scrub pine, Jersey pine)	36	30

HOW THE SEEDS WERE BURIED.

The foregoing list represents 109 species, 84 genera, and 34 families of plants. Carefully counted seeds of these samples were mixed with dry clay soil and packed in well-baked earthen pots (the common flowerpot used in greenhouses). The filled pots were covered with inverted clay saucers in order to prevent the seeds from being destroyed or becoming mixed with other seeds which might have been in the soil with which the pots were covered. By burying the seeds mixed with earth in porous clay pots of this character they were subjected to conditions almost identical with those which would exist if the seeds were buried either accidentally or by natural causes. The porous clay pots admitted of the free circulation of air and water.

The pots containing these seeds were buried at three different depths. Eight complete sets were buried from 6 to 8 inches below the surface, being covered approximately the same as would result from deep plowing. Twelve complete sets were covered to a depth varying from 18 to 22 inches, sufficiently deep in this latitude to be reasonably secure from the action of frost. Twelve more complete sets were buried at a depth varying from 36 to 42 inches where the conditions were nearly uniform, so far as the three factors which regulate the germination of seeds are concerned, namely, heat, moisture, and air (oxygen). Figure 1 shows the arrangement of the pots, which were of 6-inch, 4-inch, and 2-inch sizes, to accommodate the different kinds of seed.

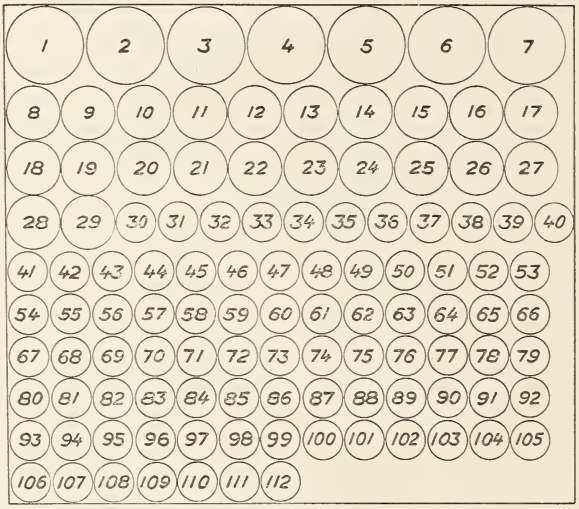

FIG. 1.—Diagram showing order in which seeds were buried.

These seeds were buried December 19 to 23, 1902, in a heavy clay soil on the Arlington Experimental Farm of the United States Department of Agriculture. With the exception of two of the duplicate samples of red clover, the seeds were of the harvest of 1902.

In each case a definite number of seeds was taken. Of the larger kinds, such as beans, peas, corn, etc., 100 seeds were used, but for the majority of the samples 200 seeds were taken. The seeds selected were for the most part of plants with which the greater number of the farmers throughout the United States are more or less familiar, either as plants of economic importance or as weeds.

In all 32 complete sets, representing 3,584 pots, were buried. One set from each of the three different depths is to be taken up as the conditions warrant and will be tested for vitality. The results of these tests are to be compared with the germination of seeds from the original bulk samples designated throughout this report as "controls."

The control samples are being stored in cloth bags in a dry room on the second floor of the Seed Laboratory. The first complete series of three sets was taken up in November, 1903, eleven months after they had been buried. The results of the first year's experiment are given in the following pages.

GERMINATION TESTS.

In making the germination tests of the buried seeds the contents of the pots, the mixture of seed and soil, were spread on sand in ordinary greenhouse flats. Along with these, in the same flats, were control samples taken from the original bulk lot of seeds, as previously mentioned. In addition, another complete set of control samples was tested in the germinating chambers of the Seed Laboratory. The temperatures given in the tables are those best suited for the germination of the different seeds.

For convenience the results of the germination tests have been divided into three groups, as follows:

A. Seeds in which the control samples, as well as those that were buried, gave only negative results when tested in the greenhouse.

B. Seeds which had either decayed or germinated and afterwards decayed while they were buried.

C. Seeds which had not completely lost their vitality while buried.

The first group, i. e., those in which both the control samples and those which had been buried failed to germinate when planted in flats in the greenhouse, consists of the following species:

1. *Axyris amaranthoides* L. (Russian pigweed).
2. *Boehmeria nivea* Guad. (ramie).
3. *Bursa bursa-pastoris* (L.) Britton (shepherd's purse).
4. *Cannabis sativa* L. (hemp).
5. *Chaetochloa viridis* (L.) Scribn. (green foxtail).
6. *Citrullus citrullus* (L.) Karst. (watermelon).
7. *Cyperus esculentus* L. (yellow nut-grass).
8. *Onagra biennis* (L.) Scop. (evening primrose).
9. *Polygonum pennsylvanicum* L. (Pennsylvania smartweed, persicaria).
10. *Polygonum persicaria* L. (lady's-thumb, smartweed).
11. *Polygonum scandens* L. (climbing false buckwheat).
12. *Sporobolus airoides* Torr. (hair-grass drop-seed).
13. *Sporobolus cryptandrus* (Torr.) A. Gray (sand drop-seed—hulled seed).

In this series the hemp should be discarded, as repeated tests failed to show any seeds from the bulk samples capable of germination. The control samples of the other seeds when tested in the germinating chambers germinated nearly as well and in some cases even better than the chamber tests which were made at the time the seeds were buried. Undoubtedly some of these seeds had decayed while buried in the soil; in fact, the watermelon seeds, *Axyris amaranthoides*, and *Sporobolus airoides* were marked "mostly decayed" when taken up. Generally speaking, the results show that the failure to germinate was not in the

seeds, but that the conditions in the greenhouse were at fault, and until other tests are made these results can not be discussed with any degree of satisfaction. On the other hand, it is certain that some of the smaller seeds failed to germinate because they were covered too deeply when sown in the flats in the greenhouse.

Polygonum scandens possibly should be classified in Table III, inasmuch as some of the seeds which were buried at depths of from 18 to 22 inches and from 36 to 42 inches showed a few sprouts at the time the seeds were taken up, but after being transferred to the greenhouse no seedlings were developed. However, the failure in the germination of the control sample of *Polygonum scandens* throws it into the first group (A) with the other two species of the same genus, i. e., *Polygonum pennsylvanicum* and *P. persicaria*.

The result of the tests of the buried seed of *Sporobolus cryptandrus*, as given in this group, should be compared with the germination of the unhulled seed as given in Table III, No. 64. The control samples of both the hulled and the unhulled seed which were sown in the greenhouse failed to germinate, but all three samples of the unhulled seed that had been buried gave some germination when tested in the greenhouse.

TABLE II.—*Results of tests of seeds which had either decayed or germinated and afterwards decayed while buried.*

Sample number.	Laboratory test number.	Kind of seed.	Chamber tests.			Greenhouse tests in sand.			
			Temperature.	Original sample.	Control.	Control.	Depth of burial.		
							6–8 inches.	18–22 inches.	36–42 inches.
			° C.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.
14	16196	Zea mays (Boone County white corn)	20–30	99.5	99	.....	.....	.....	.....
15	16197	Zea mays (sweet corn)	20–30	98.5	98.5	.....	.....	.....	.....
16	16217	Agrostemma githago	20–30	99	98.5	.....	.....	.....	.....
17	16221	Brassica oleracea	20	85.5	82	.....	.....	.....	.....
18	16244	Gossypium hirsutum	20–30	77.5	72	.....	.....	.....	.....
19	16233	Pisum sativum	20–30	99	98	.....	.....	.....	.....
20	16232	Phaseolus vulgaris	20–30	97.5	98.5	.....	.....	.....	(*a*)
21	16203	Fagopyrum fagopyrum	20–30	100	98.5	.....	(*b*)	(*c*)	.....
22	16195	Triticum aestivum	20	99	96.5	.....	(*d*)	.....	(*a*)
23	16186	Hordeum sativum	20	100	98	.....	(*d*)	(*d*)	(*d*)
24	16175	Avena sativa	20–30	70.5	91.5	95.5	0	0	0
25	16191	Secale cereale	20	100	98.5	88	0	0	0
26	16267	Cucumis melo	20–30	96.5	97	88	0	0	0
27	16199	Allium cepa	20–30	94.25	88	70.5	0	0	0
28	16270	Lactuca sativa	20–30	100	98.5	91	0	0	0
29	16281	Helianthus annuus (cult.)	20–30	97	96.5	43	0	0	0
30	16241	Linum usitatissimum	20–30	93.5	95	83.5	0	0	0
31	16245	Hibiscus militaris	20–30	98.25	92	94	0	0	0
32	16200	Asparagus officinalis	20–30	80	*e* 69	74	*f* 0	*f* 0	*f* 0
33	16177	Bromus racemosus	20–30	100	98.5	92.5	*a* 0	0	*a* 0
34	16176	Bromus secalinus	20–30	88.5	77	95.5	0	0	0
35	16181	Eleusine indica	35	78.25	91.5	75	0	0	0
36	16284	Pinus virginiana	20–30	18	6.5	43.5	0	0	0
37	16234	Robinia pseudacacia	20–30	14	*g* 11.5	3.5	0	0	0

a Many had germinated and afterwards decayed.
b Approximately 10 per cent had germinated; the remainder had decayed.
c An occasional old sprout was found.
d Approximately all had germinated and afterwards decayed.
e Clipped, 87 per cent; not clipped, 51 per cent.
f Practically all had sprouted; the sprouts from seeds buried at the 36–42-inch depth were found matted in the bottom of the pot.
g Clipped.

The corn, sweet corn, corn cockle, cabbage, cotton, peas, beans, buckwheat, wheat, and barley—the first ten samples given in the foregoing table—were all so unmistakably decayed when the seeds were taken up that the contents of the pots were thrown away, no greenhouse tests being made. The first six of these samples showed no trace of any remains of old sprouts; apparently all of the seeds had decayed before germination had taken place. If germination took place it must have been comparatively soon after burial, thus giving ample time for all of the old sprouts to decay beyond identification. This, however, seems hardly probable, considering that the seeds were buried during the latter part of December, 1902; moreover, the beans, buckwheat, and barley from some or all of the different depths showed clearly the remains of well-developed radicles.

The beans which were buried at depths of from 6 to 8 and from 18 to 22 inches had decayed, while many of those buried at a depth of from 36 to 42 inches had germinated and afterwards decayed. The buckwheat from the 6 to 8 inch depth showed that approximately 10 per cent had germinated, while at 18 to 22 inches there were only the remains of an occasional old sprout, and at 36 to 42 inches all of the seed had decayed. In the wheat the greater number of the grains that were buried from 6 to 8 and from 36 to 42 inches had germinated and then decayed, while those which were buried at a depth of from 18 to 22 inches showed only decayed seed. Approximately all of the barley at the three different depths had germinated and afterwards decayed.

The last fourteen species given in this table were marked "decayed" when the seeds were taken up, but as the conditions were not so clearly indicated as in those first mentioned, germination tests were made in the greenhouse.

The results of the germination tests show that none of the pots contained any viable seeds. Of this latter group only the pots containing the *Asparagus officinalis* and *Bromus racemosus* (Nos. 32 and 33) showed remains of old sprouts. The seeds in the other pots apparently had all decayed without any germination during the time they were buried. The germination of the asparagus seed had been almost perfect. The pot buried at the greatest depth contained only a mass of sprouts, many of which were still partially alive. The *Bromus racemosus* showed that germination had taken place only in the pots buried at 6 to 8 and 36 to 42 inches, while those buried at the depth of 18 to 22 inches had all decayed before germinating.

It is interesting to note in this connection the behavior of the two species of Bromus—*Bromus secalinus* (cheat or chess) and *B. racemosus* (upright chess). The seeds of both of these species had completely lost their vitality within the eleven months in the soil, while the control samples gave a germination of 95.5 and 92.5 per cent.

respectively. These differences are more clearly shown in Plate I, A and B.

The results above stated, while perhaps not altogether conclusive, inasmuch as they represent only single tests of 200 seeds in each case, show that seeds of these two plants will not remain viable for long periods when buried in the soil.

This is particularly interesting in the case of the common cheat or chess, which is frequently a pernicious weed in the grain fields of the United States. The generally accepted opinion is that the grains of cheat will live in the soil for a number of years, the seeds germinating when conditions are most favorable, the resulting plants then crowding out the wheat. Some people even hold that in "off seasons" wheat turns to cheat, but fortunately such erroneous ideas are fast disappearing.

The results of these experiments show that cheat, whenever found growing in grain fields or elsewhere, has come from seed recently sown and has not been lying dormant in the soil. With but few exceptions the unexpected appearance of cheat comes either from seeds that have been sown unintentionally mixed with wheat or other grains so that they passed unobserved, or from seeds that have been scattered with stable manure.

Dr. Beal[a] has also shown that buried seeds of *Bromus secalinus* do not retain their vitality for a long period of years. In Beal's experiments the first test was at the expiration of five years, but not a single grain of cheat responded to the germination test at that time.

Table II includes the majority of our more commonly cultivated plants of the field or garden, all of which failed to show any seeds capable of germination after having been buried in the soil for approximately one year. This statement will hold good for the majority of our cultivated plants. There are, however, a number of exceptions. Many of these will be found in Table III, some showing that vitality was remarkably well preserved. Of these celery, parsnip, and tobacco (numbers 94, 95, and 99, respectively) should be mentioned in particular. The highest germination in each case was 64 per cent for the celery from the 18 to 22 inch depth, 63 per cent for the parsnip from the 36 to 42 inch depth, and 70 per cent for the tobacco from the 18 to 22 inch depth.

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[a] Bulletin No. 5, Michigan Agricultural College, 1884.

TABLE III.—*Results of tests of seeds that had not completely lost their vitality while buried.*

Sample number.	Laboratory test number.	Kind of seed.	Chamber tests.			Greenhouse tests in sand.			
							Depth of burial.		
			Temperature.	Original sample.	Control.	Control.	6–8 inches.	18–22 inches.	36–42 inches.
			° C.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.
38	16185	Festuca elatior	20–30	97	83	86	0.5	0.0	a0.0
39	16257	Capsicum annuum	20–30	96	97	80	.0	.0	.5
40	16222	Brassica campestris	20	90.25	86	18.5	.0	.0	b.5
41	16239	Trifolium repens	20	84.75	42.75	86	.6	b1	.0
42	16240	Vigna catjang	20–30	82.5	59.5	70	.0	1	.0
43	16230	Lespedeza frutescens	20	15	c1	2.5	.0	.0	1
44	16246	Ascyrum hypericoides	30	1.5	.0	.0	1	.0	.5
45	16259	Lycopersicon lycopersicon	20–30	99.25	72.5	88	.5	1	.5
46	16179	Chaetochloa glauca	20–30	55.75	37.5	18	1	1	1
47	16242	Rhus glabra	20–35	.0	.0	.0	.0	.0	2
48	16268	Cucumis sativa	20–30	100	98.5	62	.0	1	3
49	16236	Trifolium pratense	20	89.75	73	85.5	2	4	4
50	16235	Trifolium hybridum	20	91.75	84	73	2	4	4.5
51	16274	Xanthium pennsylvanicum	30	50	.....	.0	.0	.0	.5
52	16229	Cassia marylandica	30	14.5	d98	20	3	3	5
53	16273	Ambrosia trifida	20–30	29	52.5	48	.0	b2	6
54	16237	Trifolium pratense (10964)	20	67.75	.....	70	4.5	b5	6
55	16219	Vaccaria vaccaria	20–35	e6.5	88	68	.0	b4	7
56	16251	Convolvulus sepium	20–30	4	2	24	2	4	7
57	16283	Rudbeckia hirta	30	65.5	78.5	74.5	6.5	6.5	7
58	16224	Erysimum cheiranthoides	20–35	52.5	42	14.5	2	b5	b8
59	16231	Medicago sativa	20	84.5	64.5	97	b2	b9	b9
60	16227	Thlaspi arvense	20–30	57.25	54.5	.5	b11	8	11.5
61	16261	Solanum nigrum	20–30	97.75	91	12	9.5	10.5	12.5
62	16213	Chenopodium hybridum	20–30	61	18.5	10.5	7.5	9.5	13
63	16253	Cuscuta polygonorum	20–30	12	8.5	55.5	11.5	10.5	13
64	16193	Sporobolus cryptandrus	30	2.25	3	.0	.5	1.5	13.5
65	16265	Plantago rugelii	20–30	3.75	5.5	67.5	12	12	13.5
66	16255	Verbena hastata	20–30	9	.5	.....	11.5	13	14
67	16220	Brassica nigra	20	1.5	13.25	34	10	b14	b14
68	16238	Trifolium pratense (hard)	20	13.75	9.25	18	b10.5	15.5	14.5
69	16184	Elymus triticoides	20–30	84	75	85	1.5	b3.5	b15.5
70	16187	Panicum virgatum	20–30	30.5	36.5	22	7	17	16
71	16174	Avena fatua	20–30	70.5	91.5	93.5	b9	b8	18
72	16211	Beta vulgaris	20–30	153	.....	90.5	7	19.5	20
73	16228	Potentilla monspeliensis	20–30	41	83	73.5	b9.5	16	21.5
74	16183	Elymus canadensis	20–30	93.5	95.5	81	.0	b7	b22
75	16190	Poa pratensis	20–30	90.75	87	59	16	22	24.5
76	16262	Verbascum thapsus	20–30	82.5	98	72.5	7	7.5	25.5
77	16182	Elymus virginicus	20–35	65.25	44	83	a2	b13.5	b25.5
78	16226	Sisymbrium altissimum	20	88.25	86.25	76	b10.5	17.5	26
79	16256	Verbena urticifolia	30	1.5	.0	56.5	23.5	24.5	26.5
80	16277	Carduus arvensis	20–30	56.75	68	5	21	22.5	28.5
81	16252	Ipomoea lacunosa	20–35	98.5	f88	88	20	25	33
82	16254	Cuscuta epilinum	20–30	.0	.0	.5	15.5	23.5	34
83	16214	Amaranthus retroflexus	20–30	94.75	91	61	18	22	35
84	16276	Bidens frondosa	20–30	75	52.5	25	29	33	36
85	16225	Neslia paniculata	20–35	96	97	68	23	24.5	38.5
86	16216	Portulaca cleracea	35	83.75	91.5	16	39	38.5	30.5
87	16272	Ambrosia artemisiaefolia	20–30	58.5	42.5	30.5	32	37	41
88	16263	Plantago lanceolata	30	82.5	78	67.5	41	41	41
89	16279	Grindelia squarrosa	20–30	25.75	41	87.5	30.5	36	42
90	16271	Taraxacum erythrospermum	20–30	85.75	87.5	85.5	35.5	41.5	45.5
91	16264	Plantago major	20–30	24	78	.0	39.5	43.5	46.5
92	16278	Chrysanthemum leucanthemum	20–30	96.25	91	85.75	b21	b33	b49.5
93	16188	Phalaris arundinacea	20–35	69.25	8	78	45	46.5	56.5
94	16248	Apium graveolens	20–30	88	83.5	72.5	48.5	64	60
95	16249	Pastinaca sativa	20–30	55.5	67	78.5	29	51	63
96	16212	Chenopodium album	20–30	67.25	58	33.5	32	63.5	64.5
97	16280	Helianthus annuus (wild)	20–30	100	97	86	43.5	64	66.5
98	16269	Lactuca scariola	20	.25	11.5	83	63.5	69	69.5
99	16260	Nicotiana tabacum	20–30	89.25	84.25	89.25	46.5	70	55
100	16173	Agropyron repens	20–30	80.24	84	23.5	20.5	b73	66.5
101	16275	Arctium lappa	20–30	99.75	96	88.5	42.5	63.5	73
102	16209	Rumex obtusifolius	20–30	97.5	95.5	80	73	72.5	79.5
103	16208	Rumex crispus	20–30	80.75	83.5	91	67.5	79.5	79
104	16215	Phytolacca americana	20–30	40.5	d88.5	84.5	7.5	66.5	80.5
105	16250	Fraxinus americanus	20–30	49.5	2	26	.0	.0	84
106	16258	Datura tatula	20–30	99	d54	88	b86	84	86.5
107	16207	Rumex salicifolius	20–30	98.25	96.5	2.5	88.5	85.5	70.5
108	16178	Chaetochloa verticillata	20–30	92.75	94.5	88.5	b58	71	90
109	16282	Onopordon acanthium	20–30	95.5	31	.0	86	93	90.5

TABLE III.—*Results of tests of seeds that had not completely lost their vitality while buried*—Continued.

Sample number.	Laboratory test number.	Kind of seed.	Chamber tests.			Greenhouse tests in sand.			
							Depth of burial.		
			Temperature.	Original sample.	Control.	Control.	6–8 inches.	18–22 inches.	36–42 inches.
			° C.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
110	16218	Alsine media	20–30	97	98.5	93	90.5	96.5	92.5
111*g*	16243	Abutilon abutilon	.....	.....	.....	.....	.....	.....	.....
112*g*	16189	Phleum pratense	.....	.....	.....	.....	.....	.....	.....
		Average percentage of germination	.....	63.2	57.5	53.2	20.5	26.5	31

a Many had germinated and afterwards decayed.
b Fresh sprouts found when samples were taken up. These sprouted seeds were not thrown away, but were transplanted with the remainder of the sample and tested in sand in greenhouse, consequently those which produced seedlings are included in the percentages of germination given in the table. These fresh sprouts were found as follows:

Sample number.	Depth.	Sprouts.	Sample number.	Depth.	Sprouts.	Sample number.	Depth.	Sprouts.	Sample number.	Depth.	Sprouts.
	Inches.			*Inches.*			*Inches.*			*Inches.*	
39	36–42	1	59	36–42	1	71	18–22	Many.	92	18–22	Many.
53	18–22	3	60	6– 8	1	73	6– 8	4	92	36–42	Many.
54	18–22	1	67	18–22	2	74	18–22	Few.	100	18–22	1
55	18–22	1	67	36–42	2	74	36–42	Many.	106	6– 8	2
58	18–22	10	68	6– 8	1	77	18–22	10	108	6– 8	Many.
58	36–42	5	69	18–22	Few.	77	36–42	5			
59	6– 8	4	69	36–42	Many.	78	6– 8	1			
59	18–22	2	71	6– 8	Many.	92	6– 8	Many.			

c Clipped seed germinated, 59 per cent.
d Clipped.
e Germinated, 84 per cent at 20° C.
f Clipped seed germinated, 100 per cent.
g Tests interrupted.

In Table III the names of the seeds are arranged in the order of their vitality as determined by the germination tests made in the greenhouse. The list of seeds tested begins with *Festuca elatior* (meadow fescue), which showed only one viable seed, that being from the 18 to 22 inch depth, and ends with *Alsine media* (common chickweed), in which nearly all of the seeds retained their power of germination throughout the entire period that they remained in the soil. The germination of the latter, when sown in the greenhouse, was almost perfect. (See Pl. II, fig. 1.)

In many instances some of the seeds had germinated while they were buried. In most cases the seeds which had germinated afterwards decayed. In the larger seeds this could usually be determined without much difficulty, but with many of the smaller seeds no such observations could be made. However, it is more than probable that many of the smaller seeds which showed a low germination when transplanted in the greenhouse had germinated and afterwards decayed before being dug up, but this could not be satisfactorily determined by a hurried field examination. Many of the pots also contained fresh

sprouts at the time the seeds were taken up. The number of fresh sprouts in each case is indicated in a footnote to Table III.

Unlike Table II, Table III includes names of but very few of our cultivated plants. The majority belong to that class of plants commonly known as weeds. These results show that but a limited number of our cultivated plants produce seeds which can retain their vitality for any length of time when buried in soil. On the other hand, the seeds of the plants which are commonly known as weeds are of strong vitality, and many of them deteriorated but very little with the treatment given. This, of course, is what we would expect. By natural selection the wild plants which survive are just those from seeds which are capable of living in the soil for a period of time more or less extended, and ultimately this factor becomes hereditary. With most of the cultivated plants the seeds are gathered and carefully saved from year to year, resulting in the loss of these inherited characteristics.

The mere fact that certain seeds retain their power of germination for a period of years when buried in the soil brands the plants which they produce as weeds. The length of time that such seeds can remain in the soil and still retain their power of germination largely determines their noxiousness. In other words, it may well be said that the pernicious character of weeds is directly proportional to the length of time the seeds will remain viable when buried in the soil. For this reason bad weeds are difficult to eradicate once the seeds are allowed to mature. (See Pl. II.)

RELATION OF DEPTH OF BURIAL TO VITALITY.

Table III shows that many of the seeds were better preserved the deeper they were buried. This is probably best explained by the difference in the three factors which govern germination, viz, *heat*, *moisture*, and *oxygen*. At the greatest depth the amount of moisture is always more uniform, the supply of air is greatly lowered, and the temperature is much reduced. The temperature decreases very rapidly as we go below the surface of the soil, and at 3½ feet is comparatively uniform throughout the year. Experiments conducted at McGill College, Montreal, Canada, by C. H. McLeod show that at a depth of 40 inches below the surface of the soil the minimum and maximum temperatures through the year were approximately 35° and 60° F., respectively.[a]

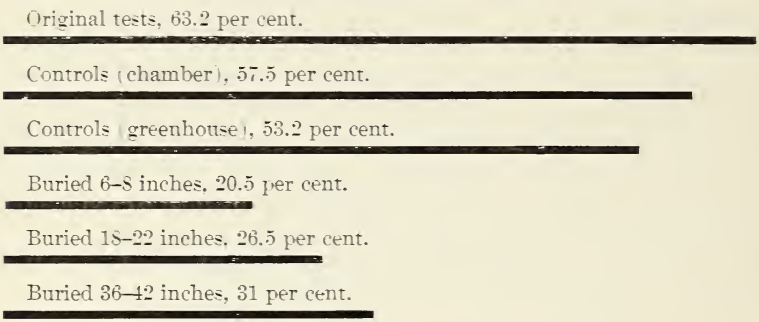
The greater number of seeds germinate best when subjected to daily alternations in temperature. These alternations do not take place at a depth of 3 feet below the surface; consequently there is a better

[a] Trans. Roy. Soc., Canada, Ser. 2, Vol. 7, Sec. III, pp. 13–16, 1901.

preservation of vitality at that depth as a result of the more dormant condition of the seeds. (See Pl. III and the diagram below.)

As was anticipated, most of the seeds which were stored in the Seed Laboratory preserved their vitality much better than those that were buried. But there are a number of cases in which the seeds were preserved practically as well in the soil as in the laboratory, the deterioration being very small in either case. However, with but few exceptions, an ample number of seeds remained germinable at the termination of the first year to produce plants in sufficient number to keep the up-to-date farmer busy for a good share of the summer in suppressing them. The average percentages of germination of all samples, including the original test and both controls, are best shown in the following diagram:

Average germination of controls and buried seeds.



HARD SEEDS.

An interesting point in these first results is in the behavior of the Trifoliums and closely related genera, including Lespedeza and Medicago. Generally speaking, these seeds are considered to be able to withstand very critical treatment, but the results of the first year's experiments show that the seeds of all of these deteriorated very greatly while in the soil.

The white clover, No. 41, germinated only 1 per cent, and showed one fresh sprout when taken up from the 18 to 22 inch depth and nothing from the shallower or deeper trenches. The red clover did but little better: No. 49, a sample of the harvest of 1902, germinated 2, 4, and 4 per cent for the three different depths of 6 to 8, 18 to 22, and 36 to 42 inches, respectively. Another sample of red clover, No. 54, germinated 4.5, 5, and 6 per cent, respectively, for the three different depths. A third sample of red clover, No. 68, germinated 10.5, 15.5, and 14.5 per cent, respectively, from the three depths. The last two samples were of Oregon-grown seed of the harvest of 1900. The original sample of this seed, No. 54, contained 51.5 per cent of

hard seed. No. 68 includes only the hard seed selected from the Oregon clover by soaking in water for 18 and then for 20 hours a portion of the original bulk sample, using only the remaining hard seed.

These results, while unsatisfactory, show clearly that it is the hard seeds in the clovers which remain over in the soil for some considerable time. The alsike clover, No. 50, behaved practically the same as the sample of red clover first mentioned. The Lespedeza, or bush clover, No. 43, gave results very similar to the white clover. The alfalfa, No. 59, gave a germination of only 2, 9, and 9 per cent, respectively, for the three different depths. But in all cases a few fresh sprouts were present when the seeds were taken up, showing that the seeds were germinating and afterwards decaying.

SEEDS OF CULTIVATED VERSUS WILD PLANTS.

A number of interesting cases showing the greater hardiness of the seeds of wild plants over those of like or closely related cultivated forms were recorded. In *Helianthus annuus* (Nos. 6 and 97) the seeds from the cultivated plant—our common sunflower of the garden—all decayed, while the seeds of the wild sunflower retained their vitality and germinated 43.5, 64, and 66.5 per cent, respectively, for the three different depths. Similarly with *Lactuca sativa* and *Lactuca scariola*, Nos. 5 and 98, respectively, the common garden lettuce seed had all decayed, while the seed of the prickly lettuce, possibly the parent of our cos varieties, germinated 63.5, 69, and 69.5 per cent, respectively, for the three different depths. Another striking example is in *Avena sativa*, No. 1, and *Avena fatua*, No. 71, the latter germinating 9, 8, and 18 per cent, respectively, for the three different depths, besides showing many fresh sprouts in the two shallower depths at the time the seeds were taken up.

Furthermore, it is not uncommon to find wide variations in different species of the same genus, even where all forms are wild, e. g., Elymus, Chaetochloa, Chenopodium, Cuscuta, Plantago, etc. But in the cases above mentioned of the cultivated and the closely related wild forms the ability of the seeds to withstand such treatment as being buried in the soil has been lost by long cultivation of the plants and the careful preservation of the seeds under artificial conditions or storage, while seeds from the wild forms can survive when buried in the soil, for it is the plants from just such seeds that have survived.

SUMMARY.

The length of time that seeds will retain their vitality when buried in the soil is of much importance in the extermination of weeds.

The seeds of many of our pernicious weeds can be destroyed by deep plowing, if the soil is left undisturbed for some time.

Seeds of the cultivated plants, with but few exceptions, lose their vitality when buried in the soil.

Seeds of the plants commonly designated as weeds retain their vitality remarkably well when buried in the soil.

In general, the pernicious character of weeds is directly proportional to the length of time the seeds will remain viable when buried in the soil.

The deeper seeds are buried, the better is vitality preserved.

Hard seeds of the same species retain their vitality much better than those with softer seed coats.

Unhulled seed, especially of the grasses, is more resistant than hulled seed, and the vitality is always better preserved.

Seeds of plants from the same genus often retain their vitality in a very different degree.

Vitality is best preserved, even in weed seeds, when the seeds are carefully harvested and stored in a dry and comparatively cool place.

PLATES.

DESCRIPTION OF PLATES.

PLATE I. Fig. 1.—*Bromus racemosus*, smooth brome grass. Fig. 2.—*Bromus secalinus*, cheat or chess. The two divisions at the right of each figure show the vigorous growth made by the check samples. In the three divisions at the left, A, B, and C, were planted the seeds which had been buried at depths of 6 to 8 inches, 18 to 22 inches, and 36 to 42 inches, respectively. The vitality of the seeds of these two species, which are considered as noxious weeds in the grain fields of the United States, was destroyed at the expiration of eleven months.

PLATE II. Fig. 1.—*Alsine media*, common chickweed. Fig. 2.—*Rumex crispus*, curled dock. Fig. 3.—*Datura tatula*, jimson weed. Seedlings from weed seeds which did not lose their vitality by burial for eleven months, as shown in the three divisions at the left of each flat, the germination being practically the same as in the case of the two check samples shown at the right of each flat.

PLATE III. Fig. 1.—*Elymus canadensis*, nodding wild rye. A, buried 6 to 8 inches—all killed; B, buried 18 to 22 inches—only one seedling shows in the figure, but the total germination was 7 per cent, as given in the table; C, buried 36 to 42 inches—germinated 22 per cent; the two check samples at the right made vigorous growth, germinating 81 per cent. Fig. 2.—*Fraxinus americanus*, white ash. A, buried 6 to 8 inches, and B, buried 18 to 22 inches—all killed; C, buried 36 to 42 inches—germinated 84 per cent; the check samples germinated 26 per cent, but the seedlings had "damped off" before the photograph was taken. Fig. 3.—*Phytolacca americana*, poke. A, buried 6 to 8 inches—germinated 7.5 per cent; B, buried 18 to 22 inches—germinated 60.5 per cent; C, buried 36 to 42 inches—germinated 80.5 per cent; the two check samples germinated 84.5 per cent.

The illustrations show that in many cases the vitality of seeds is better preserved at a depth of 36 to 42 inches than at shallower depths.

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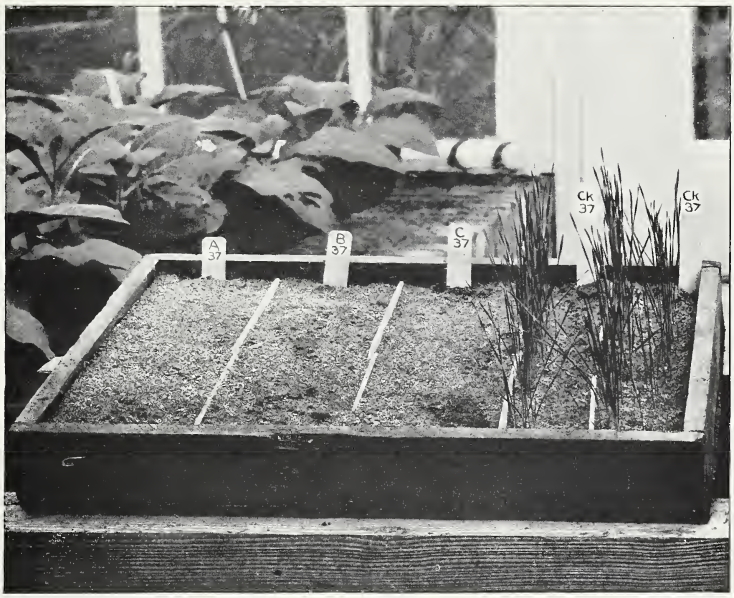

FIG. 1.—BROMUS RACEMOSUS (SMOOTH BROME-GRASS).

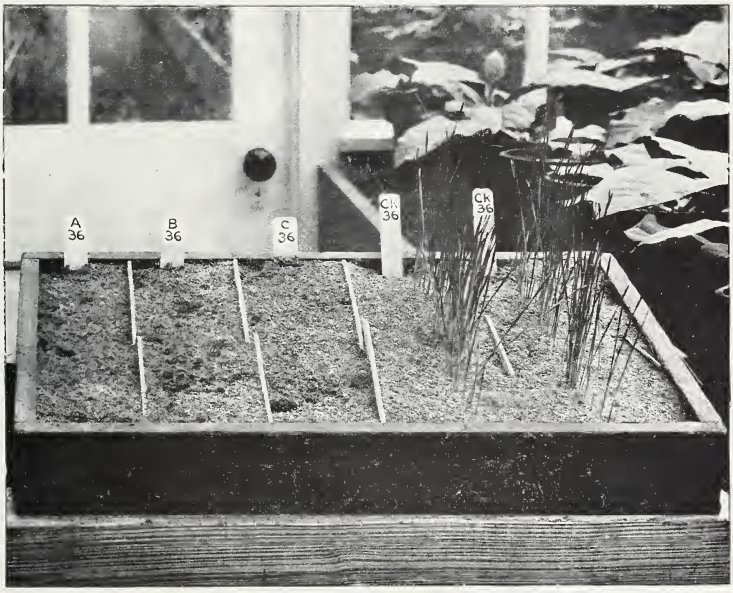

FIG. 2.—BROMUS SECALINUS (CHEAT, OR CHESS).

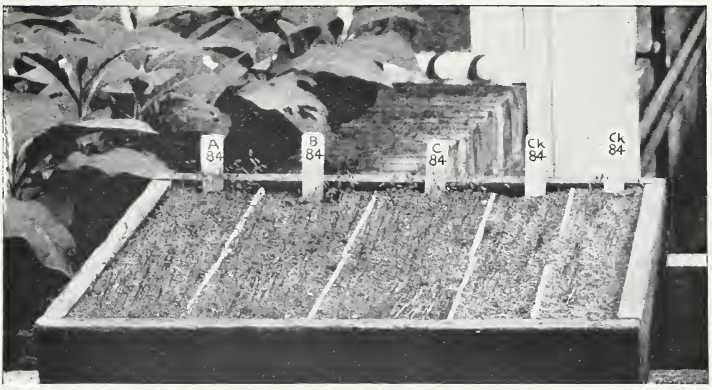

FIG. 1.—ALSINE MEDIA (COMMON CHICKWEED).

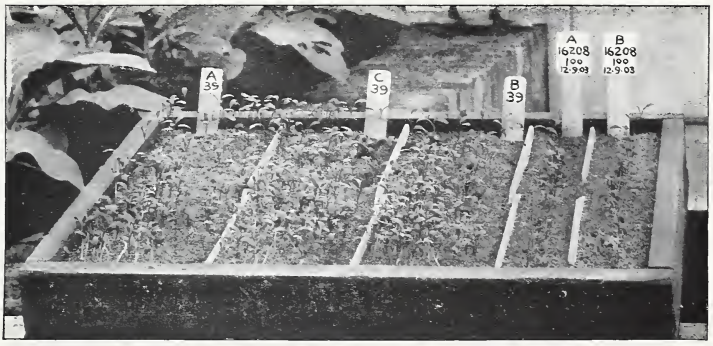

FIG. 2.—RUMEX CRISPUS (CURLED DOCK).

FIG. 3.—DATURA TATULA (JIMSON WEED).

FIG. 1.—ELYMUS CANADENSIS (NODDING WILD RYE).

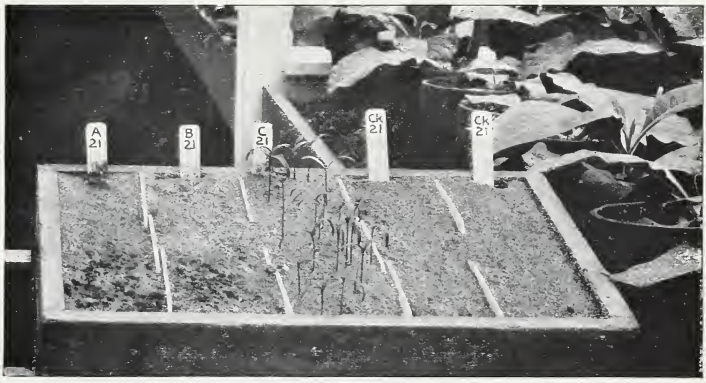

FIG. 2.—FRAXINUS AMERICANA (WHITE ASH).

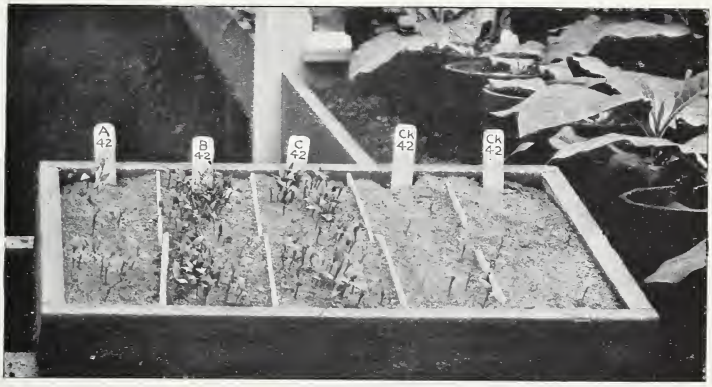

FIG. 3.—PHYTOLACCA AMERICANA (POKE).